

Past-paper walk-through

Mass Spectra of Elements ■ 1.2

eXercise

Questions in this set

- 2025 Q1
- 2021 Q2

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- **//** separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(a) An incomplete mass spectrum for magnesium is shown in the diagram.

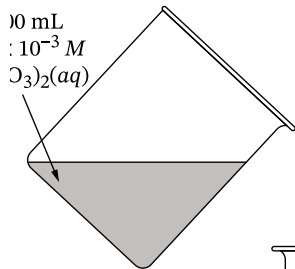
[Bar graph titled “Relative Abundance” vs. “Mass (amu)”]; y-axis from 0 to 100 in increments of 20; x-axis shows tick marks at 24, 25, 26; a single thick vertical bar is drawn at mass 24 reaching a relative abundance of about 79.]

The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

(a)(i) Complete the mass spectrum in part A by drawing thick lines in the appropriate locations to represent the percent abundance of magnesium-25 and magnesium-26.

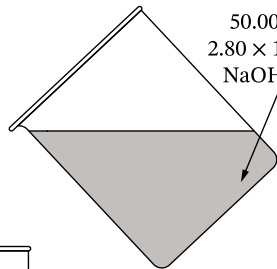
(a)(ii) Describe the difference in atomic structure that accounts for the difference in mass between magnesium-25 and magnesium-26.

Question 1



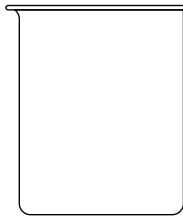
10.0 mL
 $1.0 \times 10^{-3} M$
 $\text{Ca}_3(\text{PO}_4)_2(aq)$

Beaker 1

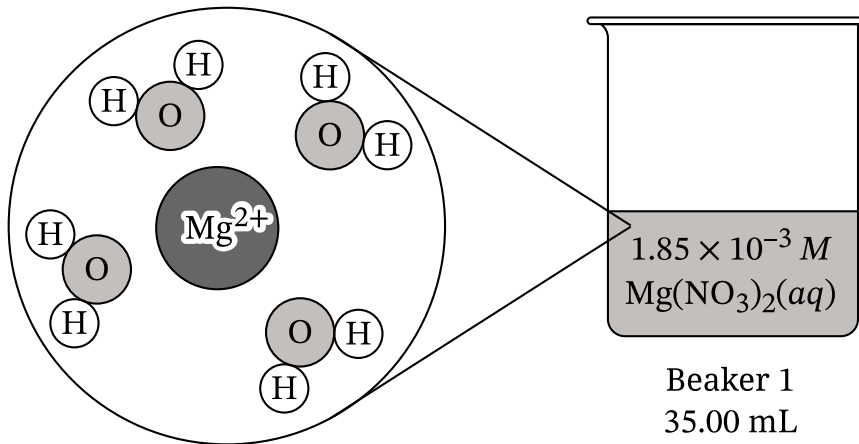


50.00 mL
 $2.80 \times 10^{-4} M$
 $\text{NaOH}(aq)$

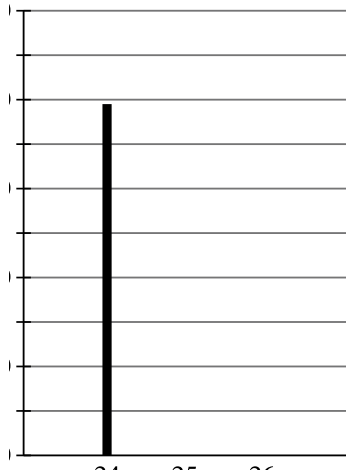
Beaker 2



Question 1



Question 1



Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(b) A student prepares a $1.85 \times 10^{-3} \text{ M}$ solution of $\text{Mg}(\text{NO}_3)_2(\text{aq})$ in beaker 1 and a $2.80 \times 10^{-4} \text{ M}$ solution of $\text{NaOH}(\text{aq})$ in beaker 2, as shown.

[Particle diagram: a magnesium ion, Mg^{2+} , at the center surrounded by six water molecules (H_2O), each oriented with its oxygen atom pointing toward the central Mg^{2+} ion and its two hydrogen atoms pointing outward.]

[Beaker 1: labeled " $1.85 \times 10^{-3} \text{ M Mg}(\text{NO}_3)_2(\text{aq})$ ", "Beaker 1", "35.00 mL".]

[Beaker 2: labeled " $2.80 \times 10^{-4} \text{ M NaOH}(\text{aq})$ ", "Beaker 2", "50.00 mL".]

The particle diagram shown represents a magnesium ion, Mg^{2+} , in beaker 1. A sodium ion, Na^+ , in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

(b)(i) The relative charge of the ions

Question 1

(b)(ii) The relative radii of the ions

Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(c) Calculate the pH of the solution in beaker 2.

Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(d) A student combines 35.00 mL of $1.85 \times 10^{-3} \text{ M}$ $\text{Mg}(\text{NO}_3)_2(\text{aq})$ with 50.00 mL of $2.80 \times 10^{-4} \text{ M}$ $\text{NaOH}(\text{aq})$, as shown in the diagram. Calculate $[\text{Mg}^{2+}]$ after the two solutions are combined but before any reaction takes place. (Assume that volumes are additive.)

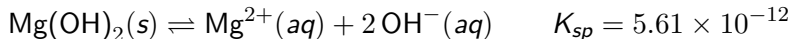
[Diagram of two conical/Erlenmeyer flasks being poured into an empty Beaker 3. Left flask: "35.00 mL", " $1.85 \times 10^{-3} \text{ M}$ ", " $\text{Mg}(\text{NO}_3)_2(\text{aq})$ ", labeled "Beaker 1". Right flask: "50.00 mL", " $2.80 \times 10^{-4} \text{ M}$ ", " $\text{NaOH}(\text{aq})$ ", labeled "Beaker 2". Both flasks have an arrow pointing down into the empty "Beaker 3" between them.]

Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(e) The dissolution of magnesium hydroxide is represented by the following equation.



(e)(i) Write the expression for the solubility product constant, K_{sp} .

(e)(ii) After the two solutions are combined in beaker 3 as described in part D, but before any reaction takes place, $[\text{OH}^{-}] = 1.65 \times 10^{-4} \text{ M}$. Using your answer to part D, calculate the value of the reaction quotient, Q .

(e)(iii) Using the reaction quotient, Q , predict whether a precipitate should form as the mixture in beaker 3 approaches equilibrium. Justify your answer.

Question 1

2025 ■ Q1

Answer the following questions about magnesium.

(f) In a separate experiment, the student adds $\text{HNO}_3(aq)$ to decrease the pH of a saturated solution containing undissolved $\text{Mg}(\text{OH})_2(s)$. Does the amount of undissolved $\text{Mg}(\text{OH})_2(s)$ increase, decrease, or remain the same as the $\text{HNO}_3(aq)$ is added? Justify your answer.

Solution 1

(a)

Mark scheme

- No separate response required — this is the context/stem describing the incomplete mass spectrum (magnesium-24 at 79% abundance) that parts (i) and (ii) below refer to.

(a)(i)

Mark scheme

- Draw two vertical bars at masses 25 and 26, each reaching a relative abundance of approximately 10 to 11 (since Mg-25 and Mg-26 together make up the remaining ~21% and are approximately equal, so roughly 10–11% each).

Solution 1

(a)(ii)

Mark scheme

- Magnesium-26 has one more neutron than magnesium-25 does (Mg-25 has 13 neutrons, Mg-26 has 14 neutrons; both isotopes have 12 protons, since they are the same element).

Solution 1

(b)

Mark scheme

- No separate response required — this is the context/stem introducing the $1.85 \times 10^{-3} \text{ M Mg(NO}_3)_2(\text{aq})$ and $2.80 \times 10^{-4} \text{ M NaOH(aq)}$ solutions (with a particle diagram of hydrated Mg^{2+}) that parts (i) and (ii) below refer to.

(b)(i)

Mark scheme

- The charge on the sodium ion (Na^+ , +1) is less than the charge on the magnesium ion (Mg^{2+} , +2). A smaller charge results in a weaker Coulombic attraction between Na^+ and water.

Solution 1

(b)(ii)

Mark scheme

- The Na^+ ion is larger (has a greater ionic radius) than the Mg^{2+} ion, so the distance between Na^+ and the oxygen atom of the water molecule will be greater. As distance increases, Coulombic attraction decreases, so Na^+ is less strongly attracted to water than Mg^{2+} .

Solution 1

(c)

Mark scheme

■ $\text{pOH} = -\log(2.80 \times 10^{-4}) = 3.553$. $\text{pH} = 14 - \text{pOH} = 14 - 3.553 = 10.447$.

Solution 1

(d)

Mark scheme

- Using $M_1 V_1 = M_2 V_2$: $M_2 = \frac{(1.85 \times 10^{-3} \text{ M})(0.03500 \text{ L})}{0.03500 \text{ L} + 0.05000 \text{ L}} = 7.62 \times 10^{-4} \text{ M}$.
So $[\text{Mg}^{2+}]$ after combining but before reaction is $7.62 \times 10^{-4} \text{ M}$.

Solution 1

(e)

Mark scheme

- No separate response required — this is the context/stem giving the $\text{Mg}(\text{OH})_2$ dissolution equilibrium and $K_{sp} = 5.61 \times 10^{-12}$ that parts (i)–(iii) below refer to.

(e)(i)

Mark scheme

- $K_{sp} = [\text{Mg}^{2+}][\text{OH}^-]^2$.

Solution 1

(e)(ii)

Mark scheme

- Using $[\text{Mg}^{2+}] = 7.62 \times 10^{-4} \text{ M}$ (from part D) and $[\text{OH}^-] = 1.65 \times 10^{-4} \text{ M}$ (given): $Q = [\text{Mg}^{2+}][\text{OH}^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$.

(e)(iii)

Mark scheme

- $Q (2.07 \times 10^{-11}) > K_{sp} (5.61 \times 10^{-12})$, so a precipitate should form.
Equivalently: the concentration of ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.

Solution 1

(f)

Mark scheme

- The amount of undissolved $\text{Mg}(\text{OH})_2(\text{s})$ will decrease. The H^+ from $\text{HNO}_3(\text{aq})$ reacts with OH^- , decreasing $[\text{OH}^-]$ and causing $Q < K_{\text{sp}}$. As a result, more $\text{Mg}(\text{OH})_2(\text{s})$ will dissolve until equilibrium is reestablished, resulting in less undissolved $\text{Mg}(\text{OH})_2(\text{s})$.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

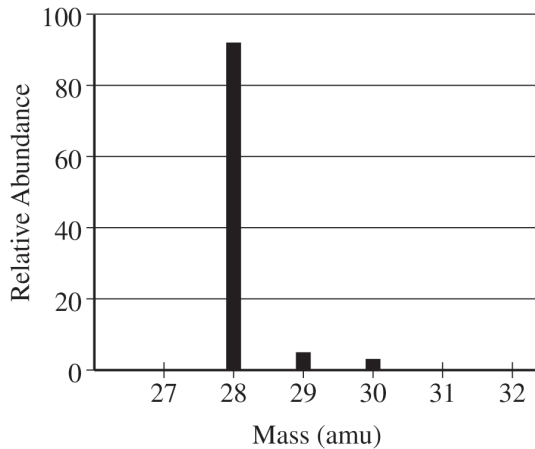
(a)(i) The mass spectrum of a pure sample of Si is shown below.

[Bar graph: Relative Abundance (y-axis, 0 to 100) vs. Mass (amu) (x-axis, 27 to 32).
A tall bar of relative abundance ~ 92 at mass 28; a very small bar at mass 29 (~ 3); a very small bar at mass 30 (~ 4); negligible/no bars at 27, 31, 32.]

How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si?

(a)(ii) Write the ground-state electron configuration of Si.

Question 2



Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(b) Two compounds that contain Si are SiO_2 and SiH_4 .

At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(c) At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.
Write a balanced equation for the reaction.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(d) A table of absolute entropies of some substances is given below.

Substance	S° (J/(mol · K))	— —	$\text{H}_2(g)$	131	$\text{Si}(s)$	18	$\text{SiH}_4(g)$	205
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Explain why the absolute molar entropy of $\text{Si}(s)$ is less than that of $\text{H}_2(g)$.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(e) Calculate the value, in $\text{J}/(\text{mol} \cdot \text{K})$, of ΔS° for the reaction.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.

[Photoelectron spectrum: Relative Number of Electrons (y-axis) vs. Binding Energy (MJ/mol) (x-axis, logarithmic scale decreasing left to right: 1,000, 100, 10, 1, 0.1). Peaks shown (from left to right, i.e. highest to lowest binding energy): a small peak near ~ 180 (between 1,000 and 100), a small peak near ~ 20 (between 100 and 10), a tall peak near ~ 10 , and a small peak near ~ 1.5 (between 1 and 0.1). No peak is shown corresponding to the $3p$ sublevel — the student must draw it in at the appropriate position and relative height.]

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

Question 2

2021 ■ Q2

Answer the following questions about the element Si and some of its compounds.

- (i)** A single photon with a wavelength of $4.00 \times 10^{-7} \text{ m}$ is absorbed by the Si sample. Calculate the energy of the photon in joules.

Solution 2

(a)(i)

Mark scheme

- The mass spectrum's tallest peak (highest relative abundance, ~92%) is at mass 28, so Si-28 is the most abundant isotope. Silicon's atomic number is 14, so this isotope has 14 protons and $(28 - 14 =)$ 14 neutrons.

(a)(ii)

Mark scheme

- Accept either equivalent form of the ground-state electron configuration of Si: $1s^2 2s^2 2p^6 3s^2 3p^2$, or the noble-gas-core notation $[\text{Ne}]3s^2 3p^2$.

Solution 2

(b)

Mark scheme

- SiH_4 is composed of discrete molecules, so the only intermolecular forces between SiH_4 molecules are (relatively weak) London dispersion forces. SiO_2 , by contrast, is a network covalent solid with strong covalent Si–O bonds extending throughout the entire structure. Because London dispersion forces are much weaker than covalent bonds, SiH_4 boils at a much lower temperature (it is already a gas at 161 K) while SiO_2 remains solid.

Solution 2

(c)

Mark scheme

- $\text{SiH}_4(g) \rightarrow \text{Si}(s) + 2 \text{H}_2(g)$ (state symbols not required; equation is already balanced).

Solution 2

(d)

Mark scheme

- $\text{H}_2(\text{g})$ molecules are more highly dispersed (able to move freely and occupy a much larger volume) than $\text{Si}(\text{s})$ atoms, and therefore have higher absolute molar entropy. Silicon is a solid, so its atoms are held in fixed positions within the lattice, are far less dispersed, and consequently have lower absolute molar entropy than $\text{H}_2(\text{g})$.

Solution 2

(e)

Mark scheme

- $\Delta S_{rxn}^{\circ} = S_{\text{products}}^{\circ} - S_{\text{reactants}}^{\circ} = [18 + 2(131)] - 205 = +75 \text{ J}/(\text{mol}_{rxn} \cdot \text{K})$,
using S° : Si(s)=18, H₂(g)=131 ($\times 2$ mol), SiH₄(g)=205, all in J/(mol · K).

Solution 2

(f)

Mark scheme

- High temperature is required so the reactant SiH_4 molecules have sufficient thermal (kinetic) energy to overcome the activation energy barrier of the reaction. A negative ΔG° (thermodynamic favorability) only indicates the reaction is spontaneous, not that it proceeds at an appreciable rate at low temperature — reaction rate is a kinetic property governed separately by activation energy.

Solution 2

(g)

Mark scheme

- The missing peak (representing the Si 3p electrons) should be drawn as the rightmost peak on the spectrum — i.e., at the lowest binding energy (below the existing 1 MJ/mol region), since 3p electrons are Si's outermost/valence electrons and thus the most weakly bound. Its height should reach the second gridline above the horizontal axis, reflecting that the 3p sublevel holds 2 electrons.

Solution 2

(h)

Mark scheme

- The valence electrons of a Ge atom occupy a higher principal energy level/shell ($n=4$) than those of a Si atom ($n=3$), so the average distance between the nucleus and the valence electrons is greater in Ge than in Si. This greater separation results in weaker Coulombic attraction between the Ge nucleus and its valence electrons, making them less tightly bound and therefore easier to remove — giving Ge a lower first ionization energy than Si.

Solution 2

(i)

Mark scheme

$$\blacksquare E = h\nu = h\frac{c}{\lambda} = (6.626 \times 10^{-34} \text{ J} \cdot \text{s}) \left(\frac{2.998 \times 10^8 \text{ m/s}}{4.00 \times 10^{-7} \text{ m}} \right) = 4.97 \times 10^{-19} \text{ J}.$$